REPORT 62PT131

GENERAL ELECTRIC COMPANY

PACIFIC GAS AND ELECTRIC COMPANY TOWER TESTS

PART III

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Information prepared for Pacific Gas and Electric Company

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Information prepared by F. J. Turner F J Turner

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PACIFIC GAS AND ELECTRIC COMPANY TOWER TESTS

PART III

INTRODUCTION

The tests reported herein are an extension of the work performed in the fall of 1961 to determine a balanced arrangement of tower insulation for the desired wet switching surge strength. The present tests were undertaken to obtain more complete knowledge of how the tower dry impulse strength is affected by number of insulators and wave shape.

In addition to the Tables and Graphs used to present the data under the "Results" section, a complete record of each voltage application is given in the Appendix.

DESCRIPTION OF TOWER AND INSULATOR STRINGS:

The tests were performed on the same mock up of the proposed PG&E tower that was used for the tests in the fall of 1961. In fact tests were started with the V string in exactly the same condition as for setup 15 when the former tests were terminated. The conditions present for this setup and also for the tests made on the outside string are shown in Figure 1. Variations in the test setup from those shown in Fig. 1 will be described as they are made during the course of the investigation.

SCOPE OF INVESTIGATION:

Five series of tests were performed as follows:

I. Impulse strike to guy wire versus distance.

II. Dry impulse flashover tests on V string versus number of insulators.

III. Dry switching surge tests on V string versus number of insulators.

IV. Dry switching surge flashover of outside phase versus number of insulators.

V. Effect of wave shape on V string flashover (26 insulators only).

In all of the investigations, critical flashover voltages and withstand voltages were determined by applying 5 or 10 waves per voltage level and increasing the voltage in small increments from the all withstand to the all flashover value. The values of the individual waves at each level were then averaged and a straight line plot made of number of breakdowns versus voltage applied. The critical flashover was then selected as that voltage where 50% of the waves would cause a flashover. This method of calculating the CFO is straight-forward with the only difficulty being experienced by flashovers occurring before crest on switching surge waves. This can lead to a voltage level averaging below the crest of the applied wave level, but the method does give the actual critical flashover voltage.

Another approach to determining the CFO is to consider only the crest value of the waves applied at a given level regardless of whether they chop before crest or not. When this is done it will increase the CFO voltage determined for switching surges about 5%, and it should be borne in mind that the actual flashover voltages are somewhat lower than indicated. This method does result in less difficulty in determining the CFO value, however.

When considering methods of interpreting and applying the data, it should be recognized that the magnitude and wave shapes of switching surges that occur on the line are not precisely known, and the statistical variation of flashover itself is fairly large. Therefore it is not practical to analyze data to one percent accuracy when the over-all variation may be as large as several percent.

TESTS AND RESULTS

Impulse Strike to Guy Wire

These tests were made to determine the flashover strength to guy wires for impulse waves, in order to permit the selection of appropriate distances to prevent direct lightning strokes from causing a flashover.

The impulse wave was obtained by using a resistance of 640 ohms in series with the .001 µf load capacitor and a resistance of 2880 ohms directly across the output of the generator. This resulted in a wave shape of 2 x 48 µsecs. The voltage applied to the tower was measured by utilizing a 10,000 ohm resistance divider which fed into a high voltage cathode ray oscilloscope.

The critical flashover voltages were determined by applying 10 waves at each level and increasing the levels in 3 to 4% steps from the all withstand to the all flashover value. Tests were made with positive polarity waves at spacings of 92", 128" and 141" from the guy wire to vibration damper, and a repeat test was made at each of the two smaller spacings. Spacings were measured to the vibration damper since this distance was found to be 4" shorter than the distance to the corona ring; also all flashovers were found to terminate on the damper. At the 92" spacing a check was made on the flashover strength with negative polarity waves, and it was found to be higher than for positive. Several insulators were broken when an attempt was made to check the negative strength at 128", therefore further negative checks were omitted. At the largest spacing of 141" a complete CFO could not be obtained because of voltage limitations of the impulse generator components. A withstand level and a one out of nine flashover level were established, however, and the CFO estimated from these falls on the straight line curve established by the tests at the two smaller spacings. These data are plotted in Figure 2, and a summary along with the weather corrections are given in Table I. On Figure 2 is also plotted the breakdown curve for a standard rod gap (from previous investigation). The curve for the guy wire strike data lies 13 to 17% above that for the rod gap. Since the conductor-to-guy configuration has a field more closely resembling that of perpendicular cylinders than it does a rod gap, it is not surprising that the breakdown strength is higher than that of the rod gap.

Dry Impulse Flashover Tests on V-String

The impulse tests on the V-string were made with the same impulse generator circuit that was used for the guy wire tests. The testing procedure varied from that used in the guy wire tests in that the tests were stopped at the first level where insulator flashovers occurred, and thus the critical flashover points were not determined. This was done to avoid the possibility of insulator breakage. All tests were made with positive polarity waves with one level of negative polarity applied to establish that negative polarity flashover is higher than positive.

With the V-string suspended as in the final setup for the 1961 fall tests (setup 15), strings of 14, 18, 22 and 26 insulators were tested by successively shorting out insulators from the ground end. For the tests on all but the 26 unit string only one side of the V was tested with 34 insulators in the other string. The 26 unit string was tested three times; 1. with 26 brown (15,000 lb.) units in the left and 34 brown in the right; 2. with 26 brown insulators in both the left and right strings, and 3. with 26 gray (25,000 lb.) insulators in the left and 34 brown in the right. The substitution of gray insulators for brown was made because several of the brown insulators were broken by flashovers. The results of the tests tabulated in Table II indicate only a 3% spread in the corrected values for these three conditions.

The critical withstand values for this test series are plotted in Figure 3. Two test points obtained inside the laboratory for twin strings of insulators are shown on the same plot. Very good agreement is indicated between the values obtained in the indoor and outdoor tests even though the configurations with respect to truss and legs were quite different.

Dry Switching Surge Flashover Tests on V-String

In order to make these test results directly comparable to the wet tests performed with setup 15 in the fall of 1961, all test conditions except the weather were made as identical as possible. The internal series resistance of the impulse generator was 25,000 ohms and the voltage was recorded by use of a capacitance divider as it was in the former tests.

In making the tests only five shots were applied per level and the increments between levels were in the order of 6 to 8%. This was also in agreement with the 1961 tests. The wave shape produced for the tests had a front in the order of 150-175 microseconds and a tail of about 3200 microseconds. In regard to the front time, it should be noted that the crest of the wave is very flat reaching about 98% of its voltage in 150 microseconds and adding the remaining 2% in the next 25 microseconds.

Dry critical flashover tests were performed on 14, 18, 22, 26, 30 and 34 insulators by successively shorting out units from the ground end in the same manner as for the previous wet switching surge tests and the impulse tests. A summary of the test results is given in Table III, and the data are plotted in Figure 4 along with the wet test values obtained during the tests last fall.

Examining the data we find that up through 30 insulators it lays on a smooth curve, but the strength for 34 insulators is no greater than that for 30 insulators.

During the tests on 34 insulators many flashovers occurred to the truss indicating that there was not enough strike in this direction. In determining the CFO the flashovers to the truss were ignored, and additional waves were applied until five of them resulted in withstands or insulator flashovers. This results in a very pessimistic value since many of the flashovers to the truss would undoubtedly be insulator withstands, if there was sufficient distance to the truss.

Dry Switching Surge Flashover of Outside String versus Number of Insulators

These tests were made to allow a direct comparison of the strengths of the outside string and the V string. It should be borne in mind, however, that the effect of hanger length was not investigated, and undoubtedly it has an effect.

The outside string was tested with 28 insulators hanging straight from a 30 inch hanger similar to setup 3b of the 1961 fall tests. The impulse generator was connected in the same manner as for all previous 175 microsecond switching surge tests, and the insulators were shorted out from the ground end in order to test 14, 18, 22, 26 and 28 units. Critical flashovers were determined for each number of insulators in the same manner as for the V string. At the conclusion of these tests, seven insulators were added and a CFO determined for the resultant string of 35 insulators.

A summary of the data for the outside string is given in Table IV, and the CFO's are shown graphically in Figure 4 along with the data for the V string. These curves show that the dry strength of the outside string is almost identical to that of the V string up through 22 insulators and is only 2% stronger for 30 insulators. Above 30 insulators the strength of the outside string continues to increase linearly, whereas that for the V string is limited because of flashovers to the truss.

It therefore appears that the dry switching surge strength of the V-string is approximately equal to that of the outside string if the tower is large enough to maintain adequate strike distance to the truss and legs.

Also plotted on Figure 4 is the one value obtained during the 1961 fall tests for the wet critical flashover strength of 28 insulators in the outside string hanging straight. This value is five percent above that for the V-string.

Effect of Waveshape on V-String Flashover

In addition to the tests with impulse and 175 µsec waves, the arcover strength of 26 insulators in the V-string was checked with waves having fronts of 50 and 350 microseconds. In each case three independent 5 shot CFO's were obtained. These data are summarized in Table V and shown graphically in Figure 5. In Figure 5, the withstand curve as well as the CFO curve is plotted because the CFO for the two microsecond waves was not determined during the tests, and therefore the CFO curve is only approximated in the impulse region. It is interesting to note from these curves that although the withstand level does not change from 50 to 350 microseconds the CFO values tend to increase slightly. This increase is only of the order of 5% and can easily be due to the spread of results. Upon examining the CFO values in the table, however, there appears to be a definite trend. Since this trend does not appear in the withstand values, there is evidently a greater spread between the CFO and withstands at the shorter times.

The curve shown in Figure 5 is somewhat misleading in that it does not show the effect of wave front alone. If the wave front only is shortened and the tail kept long as was done down to 50 microseconds, the flashovers gradually work up the front and over the crest of the wave until the great majority occur on the tail, but the flashover strength changes very little, if any. The waves with a 2 µsec front, however, were intended to represent lightning strokes rather than switching surges, and therefore the tail was shortened to 48 microseconds. With a short tail, as a streamer is propagating across the long gap the voltage is decaying; therefore the gap must be considerably overvolted before a flashover will occur.

TABLE I

GUY WIRE DRY IMPULSE FLASHOVER

Wave Shape 2.0 x 48 µsec

Date	Setup	Spacing Guy-to-Damper	δ	H_p	H_n	Positive Polarity				Negative Polarity			
						WS	WS Corr.	CFO	CFO Corr.	WS	WS Corr.	CFO	CFO Corr.
1-26	1	92"	1.052	1.120	1.104	1322	1410	1380	1470	1375	1450	1420	1495
1-29	1	92"	1.120	1.148	-	1435	1470	1475	1515	-	-	-	-
1-29	2	128"	1.09	1.147	-	2020	2125	2075	2180	-	-	-	-
2-1	2	128"	1.098	1.143	-	1935	2015	2050	2135	-	-	-	-
2-5	3	141"	1.003	1.093	-	2070	2150	2170*	2370*	-	-	-	-

*Estimated value

TABLE II

INSULATOR DRY IMPULSE SPARKOVER

Wave Shape 2.0 x 48 µsec

Date	Number of Insulators Unshorted	δ	H_p	H_n	Positive Polarity				Negative Polarity			
					WS	WS Corr.	FO*	FO* Corr.	WS	WS Corr.	FO*	FO* Corr.
2-6	14	1.08	1.144	1.124	1045	1110	1070	1185	>1125	1170	-	-
2-6	18	1.08	1.144	1.124	1345	1430	1370	1450	>1415	1470	-	-
2-6	22	1.08	1.144	1.124	1620	1720	1650	1750	>1700	1770	-	-
2-6	26	1.08	1.144	1.124	1980	2105	2040	2160	-	-	-	-
2-7	26 Both strings	1.11	1.145	-	2030	2090	2080	2145	-	-	-	-
2-9	26 Gray	1.045	1.120	1.104	1905	2040	1975	2120	1890	1995	1935	2040

* First flashover level

TABLE III

INSULATOR DRY SWITCHING SURGE SPARKOVER

Wave Shape 150 x 3200 µsec

Date	Number of Insulators Unshorted	δ	H_p	H_n	Positive Polarity				Negative Polarity			
					WS	WS Corr.	CFO	CFO Corr.	WS	WS Corr.	CFO	CFO Corr.
2-12	14	1.08	1.146	1.126	797	845	885	940	>970	1010	-	-
2-13	18	1.07	1.145	1.125	985	1055	1095	1175	>1160	1220	-	-
2-13	22	1.07	1.145	1.125	1148	1230	1195	1282	>1335	1405	-	-
2-12	26	1.08	1.146	1.126	1278	1355	1340	1420	>1470	1535	-	-
2-13	30	1.064	1.140	1.121	1335	1430	1445	1550	-	-	-	-
2-13	34	1.064	1.140	1.121	1356	1450	1450	1555	-	-	-	-

Corrected values corrected for H/δ

TABLE IV

SUMMARY OF DRY FLASHOVER TESTS ON OUTSIDE PHASE
175 x 3200 μsec waves

Date	No. Insul.	RAD	H	Withstand	WS Corr.	CFO	CFO Corr.
3/7	14	1.09	1.138	900	940	915	956
3/7	18	1.09	1.136	1016	1060	1100	1140
3/6	22	1.06	1.126	1175	1248	1235	1310
3/6	26	1.06	1.126	1255	1330	1370	1460
3/6	28	1.062	1.120	1422	1500	1450	1530
3/15	35	1.04	1.122	1505	1622	1625	1750

TABLE V

SUMMARY OF EFFECT OF WAVE SHAPE ON F.O.
Positive Polarity - 26 Insulators in V-String

Date	Wave	δ	H	WS	WS Corr.	Avg. WS	CFO	CFO Corr.	Avg. CFO
2/6	2 x 48	1.08	1.144	1980	2105		2040*	2160*	
2/7	"	1.11	1.145	2030	2090		2080*	2145*	
2/9	"	1.045	1.12	1905	2040	2078	1975*	2120*	2142
2/21	50 x 3200	1.06	1.135	1290	1380		1390	1490	
2/21	"	1.06	1.135	1290	1380		1440	1540	
2/21	"	1.06	1.135	1285	1375	1378	1375	1470	1500
2/12	175 x 3200	1.08	1.146	1280	1355		1340	1420	
2/16	"	1.07	1.14	1250	1330		1350	1440	
2/16	"	1.07	1.14	1265	1350	1345	1380	1470	1443
2/20	350 x 3200	1.065	1.123	1315	1385		1350	1425	
2/20	"	1.065	1.135	1295	1380		1345	1430	
2/21	"	1.08	1.135	1300	1365	1377	1355	1425	1427

*First flashover level - not a CFO

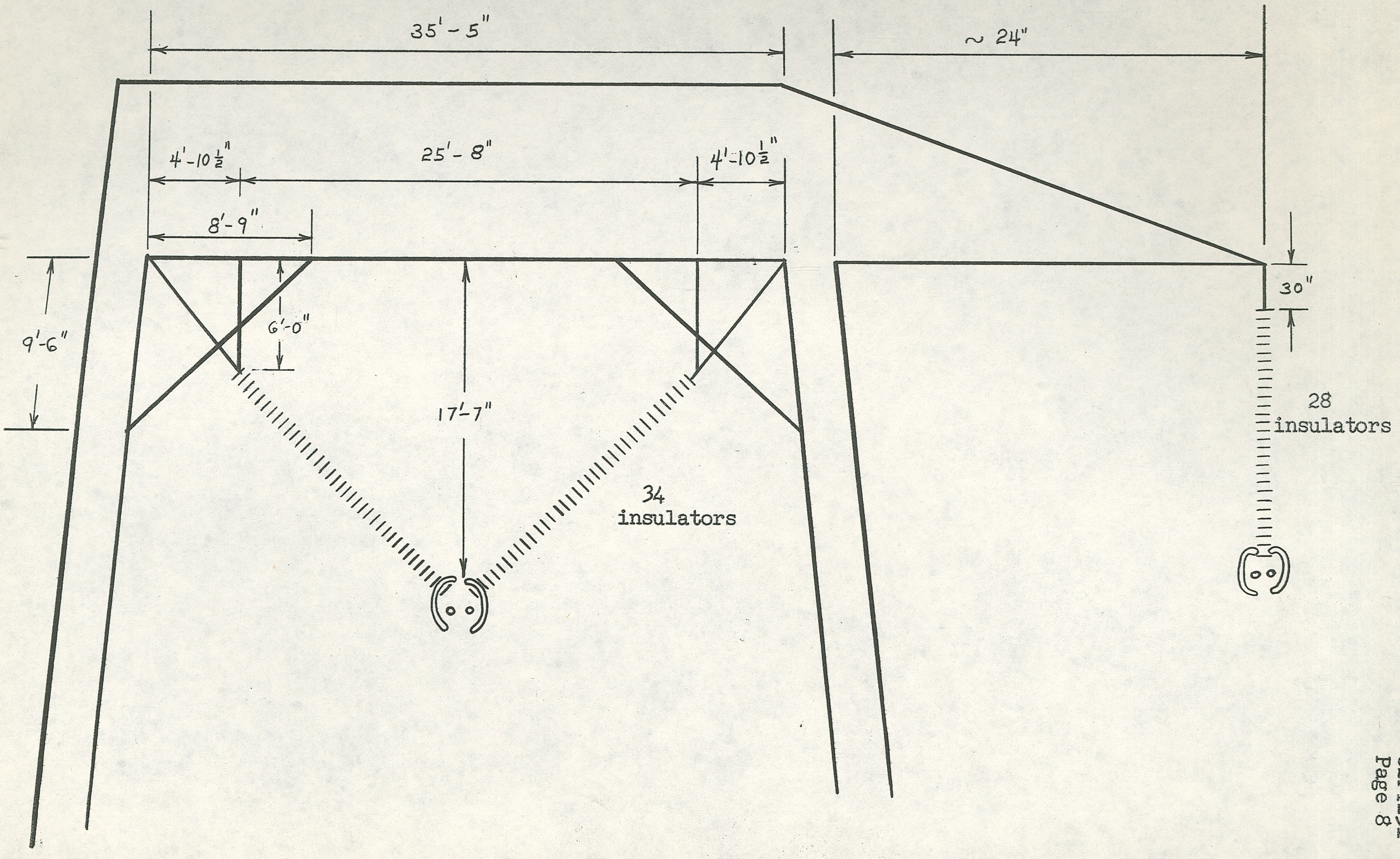


Figure 1

TOWER CONFIGURATION FOR PG&E TESTS - PART III

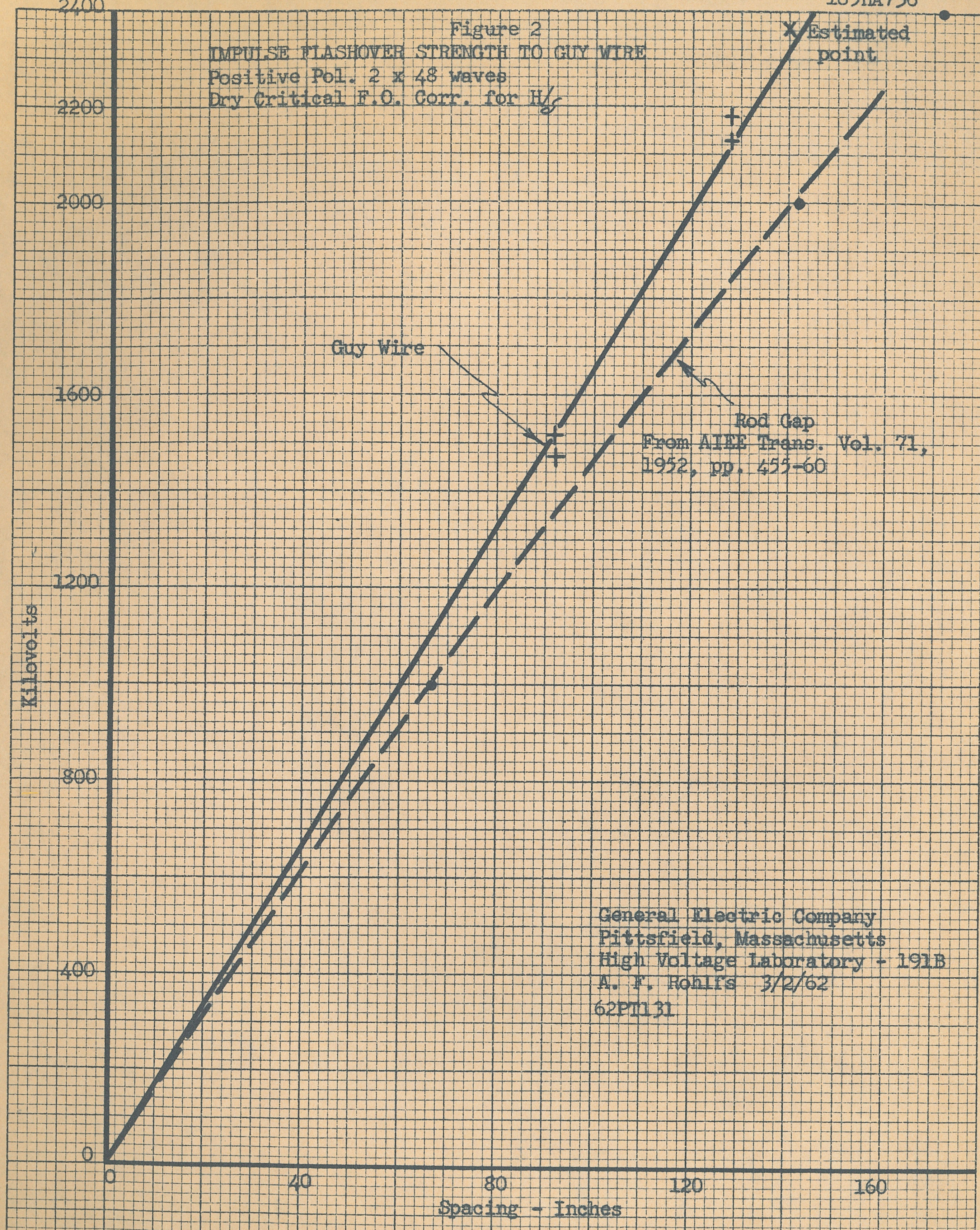


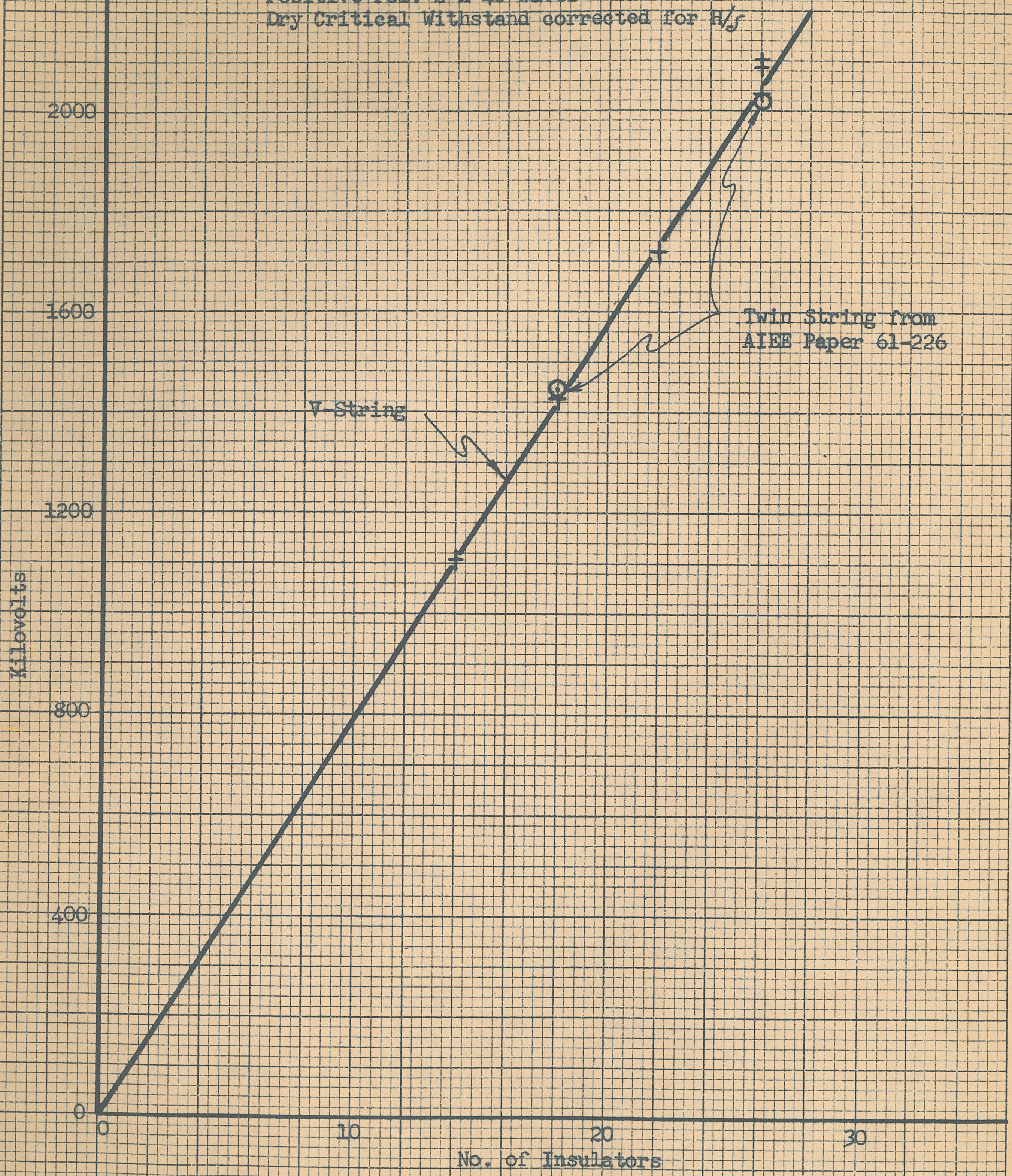
Figure 2
IMPULSE FLASHOVER STRENGTH TO GUY WIRE
Positive Pol. 2 x 48 waves
Dry Critical F.O. Corr. for H/δ

General Electric Company
Pittsfield, Massachusetts
High Voltage Laboratory - 191B
A. F. Rohlfs 3/2/62
62PT131

100X140 7/100 Inch Divisions
GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y. U.S.A.
FN-521-B, (8-50)

185HA737

Figure 3
IMPULSE FLASHOVER STRENGTH OF V-STRING INSULATORS
Positive Pol. 2 x 48 Waves
Dry Critical Withstand corrected for H/δ



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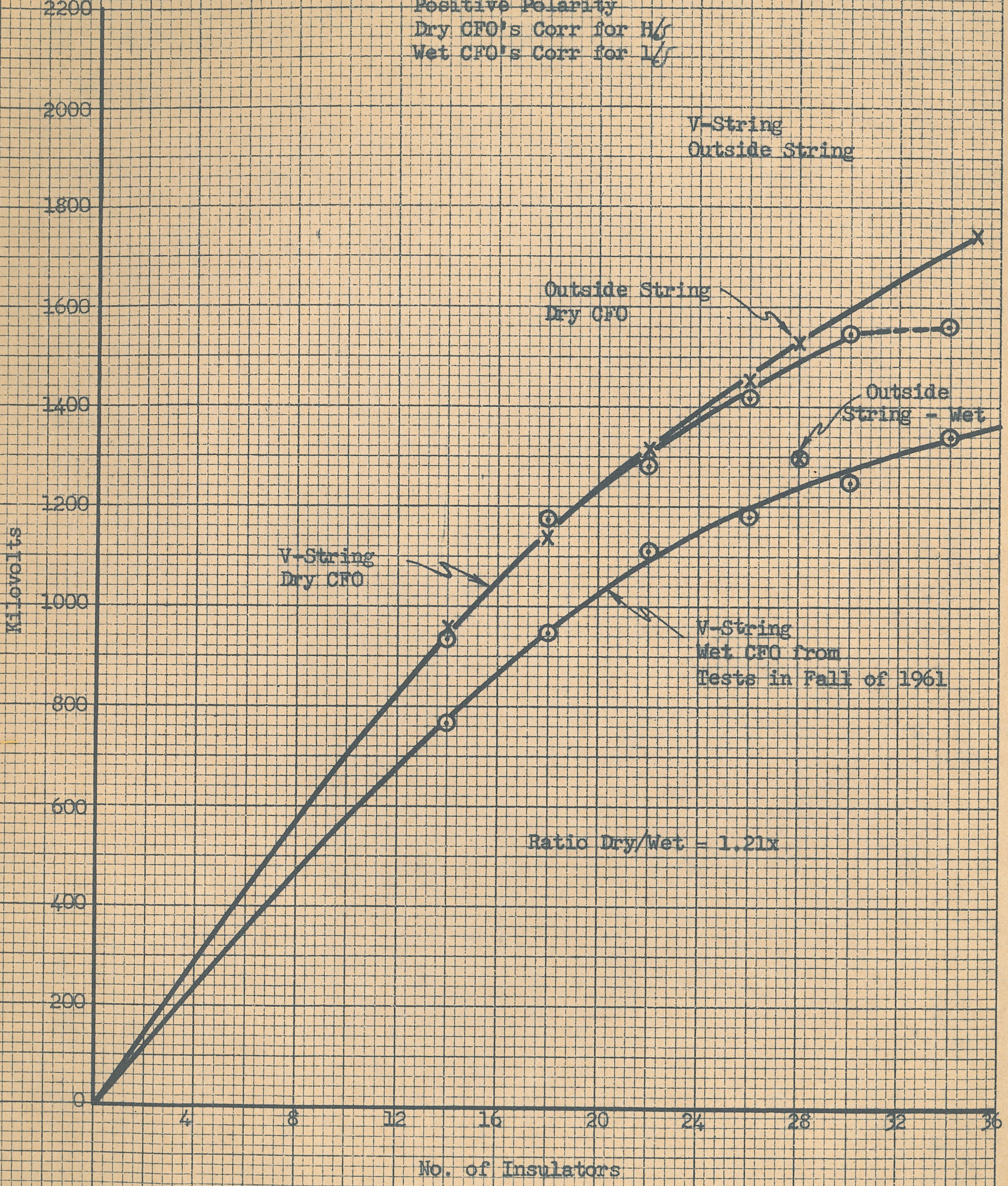
185HA737

100X140 7/100 Inch Divisions
GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U.S.A.
FN-521-B (8-50)

Figure 4
INSULATOR SWITCHING SURGE FLASHOVER DATA
175 x 3200 Waves
Positive Polarity
Dry CFO's Corr for H/δ
Wet CFO's Corr for 1/δ



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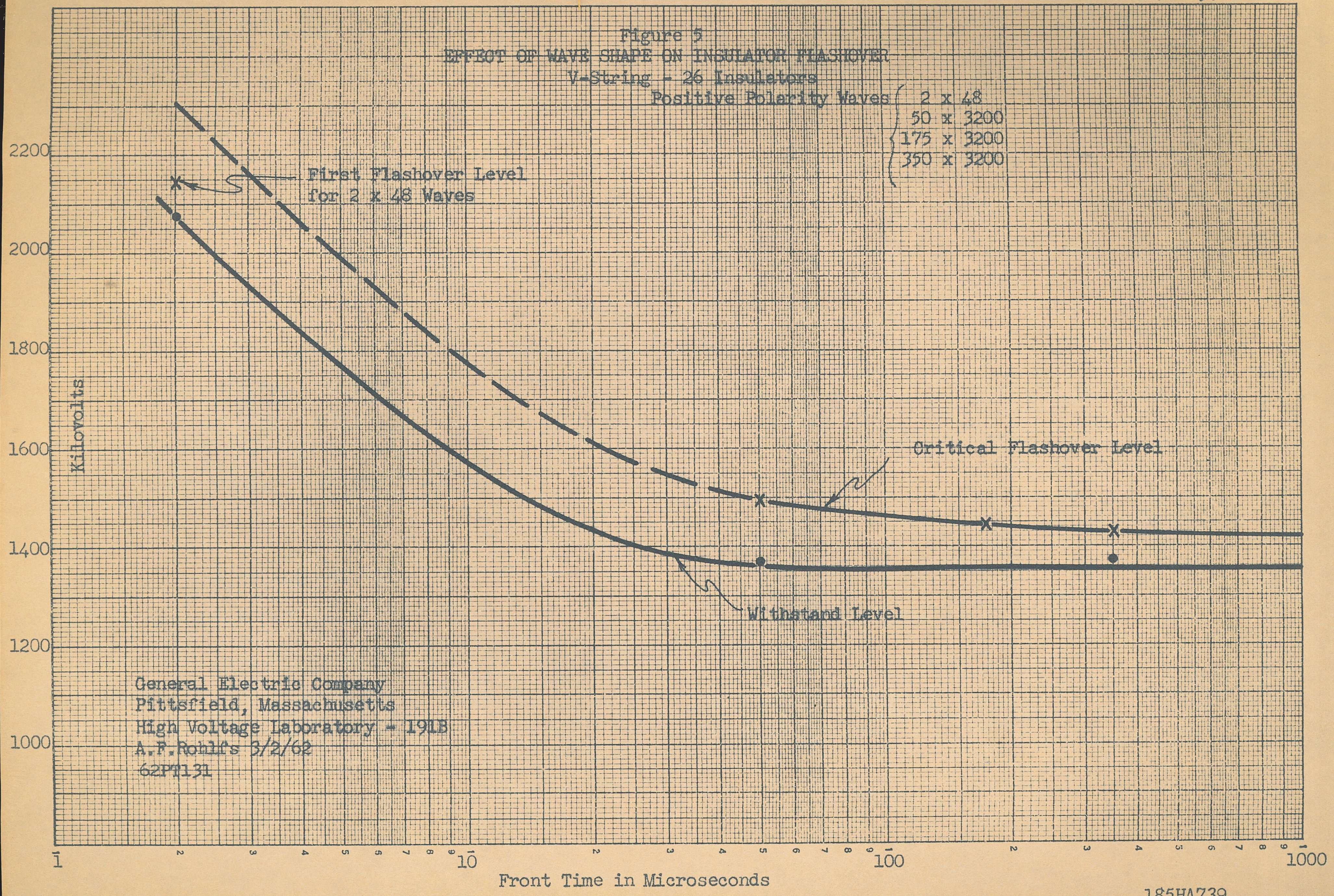

Figure 5
EFFECT OF WAVE SHAPE ON INSULATOR FLASHOVER
V-String - 26 Insulators
Positive Polarity Waves { 2 x 48, 50 x 3200, 175 x 3200, 350 x 3200

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Pittsfield, Massachusetts
High Voltage Laboratory - 191B
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62PT131

APPENDIX

The following tabulated data are a complete record of the individual impulse waves applied during the tests. They are included here to allow further analysis of the data where desired. Flashovers of the component being tested (insulators or guy wire) are placed in parentheses. Flashovers to other components are indicated as follows:

Truss - T

Legs - L

Guy Wire - G (when not being tested)

Capacitor Stack in Bubble - C

Insulators Over Top of Bubble - B

Insulators in V-String Not Under Test - I

PACIFIC GAS AND ELECTRIC

IMPULSE TESTS (2.2 x 48 μs) ON GUY WIRE STRIKE

1/26/62 92" Guy to Damper Light Snow

Bar. 29.01" Hg
Dry Bulb 34F
Dew Point 25F
Vapor Press. 0.13" Hg

Positive Polarity

Avg. KV	Individual Shots*									
	1	2	3	4	5	6	7	8	9	10
1322	1330	1290	1330	1340	1310	1310	1330	1340	1330	1310
1328	1335	1335	1320	1320	1290	1290	1360	1330	(1340)	1360
1360	1350	1350	1365	(1365)	1365	(1365)	(1365)	1365	1350	1365
1420	1420	(1420)	1430	1420	(1420)	(1420)	(1420)	(1420)	(1430)	1400
1448	(1450)	(1450)	(1450)	(1440)	(1440)	(1450)	(1450)	(1450)	(1450)	(1450)

CFO = 1380; σ - 1.052; H - 1.12
All flashovers to damper

Negative Polarity

1375	1370	1370	1370	1370	1370	1380	1380	1380	1380	1380
1441	(1440)	(1450)	(1440)	1440	(1440)	(1440)	(1440)	1440	(1440)	1440

CFO = 1420; σ - 1.052; H - 1.104

1/29/62 92" Guy to Damper Clear Day

Bar. 29.14" Hg
Dry Bulb 8.5F
Dew Point -5F
Vapor Press. .029" Hg

Positive Polarity

1436	1430	1430	1430	1430	1430	1430	1450	1430	1450	1450
1465	1480	(1460)	1460	1460	1450	1460	1460	1480	1460	(1480)
1485	(1490)	(1460)	(1490)	(1470)	1470	(1490)	(1510)	(1510)	(1490)	1470
1511	(1490)	(1510)	(1510)	(1520)	(1490)	(1510)	(1490)	(1530)	(1530)	(1530)

CFO = 1475; σ - 1.12; H - 1.15
All flashovers to damper

1/29/62 128" Guy to Damper Clear Day

Bar. 29.10" Hg
Dry Bulb 18F
Dew Point -4F
Vapor Press. .031" Hg.

Positive Polarity

2020	2020	2000	2020	2000	2000	2020	2060	1980	2060	2060
2130	(2130)	(2110)	(2120)	(2140)	(2100)	(2140)	(2120)	(2140)	(2140)	(2140)

CFO = 2075; σ - 1.09; H - 1.15
All flashovers to damper

Negative Polarity

2130	2120	2140	2130	Flashovers at bubble at about 20 μs

* ( ) indicates flashover.

Impulse Tests (2.2 x 48 μs)

1/30 - 1/31/62

Measured voltage at tower and bubble simultaneously - checked each other within 2%.

2/1/62 Repeat tests on 128" Guy to Damper Clear Day

Bar. 29.06
Dry Bulb 16.0
Dew Point 3.4
V.P. .045

Positive Polarity

Avg. KV	1	2	3	4	5	6	7	8	9	10
2024	2022	2022	2022	2032	2022	2022	2032	2022	2022	2022
2123	(2120)	(2120)	(2120)	(2120)	(2120)	(2120)	(2120)	(2120)	(2120)	(2145)
1934	1935	1955	1935	?	1870	1955	?	1910	1910	2000

CFO 2050; δ - 1.10; H-1.143
All flashovers to damper

2/5/62 141" Guy to Damper Clear Day

Bar. 28.50
Dry Bulb 50.0
Dew Point 37.4
V.P. 0.224

Positive Polarity

Approx.
2120 (2120) Couple capacitors failed
2120 8 withstands

2070	2070	2070	2070	2070	2070	2070	2070	2070	2070	2070

Withstand 2070; δ -1.003; H-1.095

Tests on Setup 15

(Flashovers are all over the insulators)

2/6/62 14 Units in West side of V-String

Clear Day

Positive Polarity

Bar. 28.81
Dry Bulb 20.0
Dew Point 4.0
Vapor press.0.044

Avg. KV	1	2	3	4	5	6	7	8	9	10
1045	1040	1030	1050	1040	1040	1070	1040	1050	1050	1040
-	(1050)	(1100)								

Withstand 1045; δ = 1.075; H = 1.144

Negative Polarity

Avg. KV	1	2	3	4	5	6	7	8	9	10
1125	1130	1110	1130	1130	1090	1130	1130	1140	1130	1130

18 Units in West side of V-String

Positive Polarity

Bar. 28.81
Dry Bulb 18.0
Dew Point 4.0
Vapor press. 0.044

Avg. KV	1	2	3	4	5	6	7	8	9	10
-	1370	1370	(1370)	1370						
1344	1340	1340	1340	1340	?	1340	1340	1340	1360	1360

Withstand 1344; δ = 1.08; H = 1.144

Negative Polarity

Avg. KV	1	2	3	4	5	6	7	8	9	10
1415	1340	1400	1400	1430	1430	1430	1430	1430	1430	1430

22 Units in West side of V-String

Positive Polarity

Avg. KV	1	2	3	4	5	6	7	8	9	10
-		1650	1650	(1650)	Knocked porcelain off 20th unit from line end.					

22 Units in East side of V-String

Positive Polarity

Avg. KV	1	2	3	4	5	6	7	8	9	10
1620	1610	1610	1610	1625	1625	1625	1625	1625	1625	1625

Withstand 1620; δ = 1.08; H = 1.144

Negative Polarity

Avg. KV	1	2	3	4	5	6	7	8	9	10
1700	?	?	?	?	?	1700	1700	1700	1700	1700

?= no pictures. All waves are withstands.

26 Units in East side of V-String

Bar. 28.81
Dry Bulb 12.0
Dew Point 4.0
Vapor press. 0.044

Positive Polarity

Avg. KV	1	2	3	4	5	6	7	8	9	10
1980	1980	1980	1910	2030	1980	2000	1980	1980	1980	1980
-	2050	2050	(2030)							

Withstand 1980; δ = 1.095= H = 1.144

IMPULSE TESTS

2/7/62 26 Unit "V" String (Both Sides)

Positive Polarity

Bar. 29.19
Dew Point 4°F
Dry Bulb 12°F
Vapor press. .069

Avg. KV	1	2	3	4	5	6	7	8	9	10
2030	2025 2075	2025 (2075)	2025	2025	2025	2025	2025	2050	2025	2050

Withstand 2030 δ= 1.11 H = 1.145

On negative polarity, damage occurred in west side string - changed to gray insulators on west side.

2/9/62 26 Unit Gray String (West Side)

Positive Polarity

1905	1895 (1975)	1895	1915	1895	1915	1915	1915	-	-	-

Withstand 1905: δ = 1.045; H ; 1.120

Bar. 28.89
Dew Point 24°F
Dry Bulb 35.5°F.
Vapor press. .123

Negative Polarity

1890	1895 -	1895 (1935)	1895	1895	1855	1895	1895	1895	1915	-

Withstand 1890; δ = 1.068; H_N; 1.105

SWITCHING SURGE TESTS

Wave Shape 175x3200 μsec.

2/12/62 26 Unit Gray String (West Side)

Bar. 29.06
Dew Point-2.2 °F
Dry Bulb 26°F.
Vapor press. 0.34

Positive Polarity

Avg. KV	1	2	3	4	5
1350	(-)	1335	(1350)	1350	1365
1275	1290	(1230)	1275	1290	1275
1278	1290	1275	1275	1275	-

Guy wire FO's at 1440 and 1380 KV

Note: Guy wires removed

Avg. KV	1	2	3	4	5
1412	(1410)	(1425)	(1410)	(1380)	(1440)

1440 - FO of 34 Brown Ins.

Withstand 1275 CFO 1340
δ 1.08 H 1.146

Negative Polarity

Avg. KV	1	2	3	4	5
1470	-	1470	-	-	1470

Withstand >1470 δ 1.08 H 1.126

2/12/62 14 Unit Gray String (West Side)

Bar. 29.06
Dew Point-2.2°F
Dry Bulb 26°F
Vapor press .034

Positive Polarity

905	925	925	(855)	935	(890)
856	(836)	862	862	855	862
797	800	800	800	793	793
926	(940)	(932)	(950)	(932)	(870)

Withstand 797 CFO 885 δ 1.08 H_p 1.146

Negative Polarity

970	-	-	970	960	980

Withstand > 970 δ 1.08 H_n 1.126

SWITCHING SURGE TESTS

Wave Shape 175x3200 μsec.

2/13/62 18 Gray Insulators (West Side)

Positive Polarity

Avg. KV	1	2	3	4	5
1100	(1065)	1080	1125	1125	(-)
1045	1065	1065	(1005)	(1020)	1065
985	990	975	990	990	975
1165	(1160)	1200	(1142)	(1190)	(1130)
1155	(1142)	(1220)	(1190)	(1085)	(1142)

Withstand 985 CFO 1095 δ 1.068 H_P 1.145

Negative Polarity

1160	-	1160	-	1160	1160

Withstand > 1160

2/13/62 22 Gray Insulators (West Side)

Positive Polarity

1252	(-)	(1245)	(1245)	(1260)	(1260)
1207	1260	(1190)	(1205)	(1175)	(1205)
1148	1160	1145	1145	1145	1145

Withstand 1148 CFO 1195 δ 1.068 H_P 1.145

Negative Polarity

1355	1350	-	1350	-	1365

Withstand > 1355 δ 1.068 H_N 1.125

SWITCHING SURGE TESTS (175 x 3200 μsec)

Bar. 29.22
DB 34 F
DP 7 F
VP .054

2/13/62

30 Gray Insulators
Positive Polarity

Avg. KV	1	2	3	4	5	6	7	8	9	10
1402	1440T	(1395)	1425	1365T	1380	(1410)	-			
1335	1350	1335	1335	1320	1335					
1500	1500T	1485T	-	1485T	(1470)	1515	1485T	1500T	1500	1515
1542	1600T	(1530)	1560T	1560T	1530T	(1560)	1545T	1545T	1560I	(1530)
	1560T	(1545)	1530T	1530T	(1545)					

CFO = 1445, δ = 1.064; H = 1.14

Negative Polarity

1605 7 withstands obtained; no pictures, voltage calculated from charge. δ = 1.064, H = 1.121

2/13/62

34 Insulators
Positive Polarity

1521	1545T	(1515)	1530T	1515T	(1515)	1545L	1515T	1515T	(1515)	(1530)
	1530L	(1530)								
1440	1440	(1440)	(1440)	1440	1440					
1356	1365	1365	1350	1350	1350					

CFO = 1450, δ = 1.064 H = 1.14

T = flashovers to truss
I = flashover 34 unit east string
L = flashover to leg of tower

REPEAT TESTS ON 26 INSULATORS - 175 x 3200 Waves

2/16/62 Positive Polarity Trial 2

Bar. 29.03
DB = 25 F
VP = 0.062

Avg. KV	1	2	3	4	5	6	7	8	9	10
	Individual Shots									
1249	1260	1205	1260	1260	1260					
1344	(1340)	(1340)	1350	1350	1340					
1383	-	(1380)	(1370)	(1400)	1410T	-				

CFO = 1350; δ = 1.07, H = 1.14

Trial 3 2/16

1263	1260	1260	1260	1275	1260	
1335	(1335)	(1320)	1335T	1350	(1320)	1350
1432	(1425)	1440	(1400)	1425T	1455	1440
1467	(1470)	(1440)	(1470)	(1515)	(1440)	

CFO ; 1380; δ ; 1.07; H ; 1.14

TESTS WITH 350 μsec FRONT ON 26 INSULATORS
Positive Polarity

Trial #1 2/20

Bar = 28.87
DB = 27
VP = 0.104

1314	1315	1305	1315	1315	1315		
1370	(1370)	1380	1360	1370	1370		
1344	(1330)	(1330)	(1330)	(1300)	1430		
1354	(1390)	(1310)	(1410)	(1330)	1410I	1430I	(1330)

CFO = 1350; δ = 1.065; H = 1.123

Trial #2 2/20

Bar = 28.87
DB = 27
VP = .075

1295	1295	1295	1295	1295	1295	
1340	(1340)	1380	1380	1370	(1250)	
1358	1430	(1380)	(1380)	(1290)	(1310)	
1387	(1435)	(1365)	1415T	(1435)	(1355)	(1345)

CFO = 1345; δ = 1.065; H = 1.135

26 INSULATORS - 350 μsec FRONT

Trial 3 2/21

Bar. = 29.2
DB = 26.0
VP = 0.076

Avg.	Individual Shots									
KV	1	2	3	4	5	6	7	8	9	10
1349	1385	-	1250	(1375)	1385					
1302	1300	1300	1300	1300	1310					
1341	1465	(1325)	(1325)	(1280)	(1310)					
1420	1530	(1355)	1520	1435T	(1340)	(1355)				
1397	(1395)	(1445)	(1330)	1500T	(1490)	(1325)				

CFO = 1355; δ = 1.08; H = 1.135

TESTS WITH 50 μsec FRONT - 26 INSULATORS
Positive Polarity

Trial #1 2/21

Bar. = 29.1
DB = 31
VP = 0.075

1358	1350	1360	1360	1370	(1350)
1450	(1450)	(1450)	(1450)	(1450)	(1450)
1290	1290	1290	1290	1290	1290

CFO = 1390 δ = 1.06; H = 1.135

Trial #2 2/21

1290	1290	-	-	1290	1290
1360	1370	(1360)	1370	1340	1360
1444	(1450)	1450	1420	(1450)	(1450)
1537	(1530)	1530	(1540)	(1520)	(1565)
1600	(1615)	(1570)	(1590)	(1615)	(1615)

CFO = 1440; δ = 1.06; H = 1.135

Trial #3 2/21

1285	1290	1300	1265	1290	1280
1364	(1380)	(1320)	1370	(1360)	(1390)
1428	1440	(1420)	(1450)	(1370)	(1460)
1526	(1520)	(1530)	(1530)	(1520)	(1530)

CFO = 1375; δ = 1.06; H = 1.135

SWITCHING SURGE TESTS (175 x 3200 μsec)
34 Insulators Positive Polarity

Trial #1 2-28-62

Bar. = 29.2
Amb. = 19°F
DP = -2.0°F
VP = .034

Avg. KV	Individual Shots 1	2	3	4	5	6	7	8	9	10	11
1400	1390	1390	-	1410	1410						
1438	(1425)	(1440)	1455	1435	1435						
1482	(1500)	1485T	1470T	1485T	(1500)	(1500)	(1500)	1410			
1485	(1515)	1410T	1410	1485T	(1500)	(1500)	(1500)	1530T	1515T	1500T	(1485)

CFO = 1450; $\delta = 1.090$; H = 1.146

Trial #2

Bar. = 29.2
Amb. = 19°F
DP = -2.0°F

1410	1410T	(1410)	(1410)	1425T	1365T	1410	1410T	1410	1410
1368	1365	1365	1365	1365	1365T	1380			
1452	(1455)	(1455)	1455T	1440T	1440T	1455	1455	1455T	(1440)

CFO = 1435 $\delta = 1.090$; H = 1.146

Trial #3

Bar. = 29.2
Amb. = 19°F
DP = -2.0°F

1368	-	1365	1365	1365	(1380)			
1330	1335	1320	1335T	(1335)	1335	1335		
1290	-	1290	1290	1290	1290			
1420	1420	1420	1420	1420	1410T	1420		
1446	1450	(1440)	(1440)	1450	(1450)	(1450)		
1485	(1485)	(1485)	1470T	(1485)	(1485)	1485T	1485T	(1485)

CFO 1400; $\delta = 1.090$; H = 1.146

SWITCHING SURGE TESTS (175 x 3200 µsec)

3/6/62 and 3/7/62

Vertical String of Gray Insulators on End of Truss

No. Insul.	Individual Shot 1	2	3	4	5	Avg. KV
	900	900	900	900	900	900
14	956	(845)	956	(892)	(892)	908
	(882)	(882)	(918)	(845)	(910)	887

CFO = 915; δ = 1.090; H = 1.138

Bar. = 29.08
Amb. = 38°F
DP = 11.3°F
VP = .066

No. Insul.	Individual Shot 1	2	3	4	5	Avg. KV
	1010	1025	1010	1025	1010	1016
18	1085	1085	1085	(1040)	1085	1076
	(1060)	(1085)	(1070)	1150	1165	1106
	(1120)	(1100)	(1070)	(1055)	(1070)	1083

CFO = 1100; δ = 1.090; H = 1.136

Bar. = 29.07
Amb. 38°F
DP = 12.4°F
VP = .070

No. Insul.	Individual Shot 1	2	3	4	5	Avg. KV
	1175	1175	1175	1175	1175	1175
22	(1210)	1255	(1200)	1255	1255	1235
	1300	(1210)	1315	(1300)	1300	1285
	(1320)	(1260)	(1365)	(1285)	(1285)	1303

CFO = 1235; δ = 1.060; H = 1.126

Bar. = 28.95
Amb. = 29.5°F
DP = 21.2°F
VP = .108

No. Insul.	Individual Shot 1	2	3	4	5	Avg. KV
	1255	1255	1255	1255	1255	1255
26	(1320)	1350	1335	1335	1335	1335
	(1380)	(1455)	1455	(1350)	(1425)	1413
	(1425)	(1410)	(1410)	(1380)	(1410)	1407

CFO = 1370; δ = 1.060; H = 1.126

Bar. 28.95
Amb. 29.5°F
DP 21.2°F
VP = .108

No. Insul.	Individual Shot 1	2	3	4	5	Avg. KV
	1425	1425	1425	1425	1410	1422
28	1470	1470	(1440)	1470	1470	1464
	(1455)	(1455)	(1455)	(1470)	(1515)	1470

CFO = 1450 δ = 1.062; H = 1.120

Bar. 28.96
Amb. = 29.0°F
DP = 22.1°F
VP = .113

SWITCHING SURGE TESTS (175 x 3200 µsec)
on 35 Insulators Hanging Vertical on End of Truss
Positive Polarity

Bar. = 28.90
DP = 23.7°F
DB = 38.0°F
VP = .122

Avg. KV	Individual Shot 1	2	3	4	5	6	7	8	9	10
1505	1505	1505	1505	1505	1505					
1595	1575	1575	(1560)	1560C	1610	(1610)	(1635)	1590C	1590C	1610C
	1590	1610	(1575)	1610						
1661	(1650)	(1665)	(1650)	1665C	1650B	1665B	1665C	1670	1670B	1670
1691	1710B	1710C	(1700)	1700C	1710B	(1700)	1710B	(1700)	1700B	1710B
	(1665)	1700B	1710B	1710B	1710B	1710C				

CFO = 1625; δ = 1.040 H = 1.122

B = Insulator supporting bubble from EHV tower flashed over

C = Circuit inside bubble flashed over